Linearisation, Error Correction Coding and Equalisation for Multi-Level Modulation Schemes

A thesis

submitted in fulfilment

of the requirements for the degree

of

Doctor of Philosophy

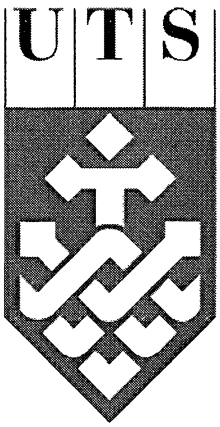
at the

University of Technology, Sydney

by

YounSik KIM

Department of Information & Communication Group, Faculty of Engineering



P.O. Box 123, Broadway, NSW 2007, Australia (yskim@eng.uts.edu.au)

March 29, 2005

Certificate of Authorship/Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

April 14, 2005

Abstract

Orthogonal frequency division multiplexing (OFDM) has been standardised for digital audio broadcasting (DAB), digital video broadcasting (DVB) and wireless local area networks (WLAN). OFDM systems are capable of effectively coping with frequency-selective fading without using complex equalisation structures. The modulation and demodulation processes using fast fourier transform (FFT) and its inverse (IFFT) can be implemented very efficiently. More recently, multicarrier code division multiple access (MC-CDMA) based on the combination of OFDM and conventional CDMA has received growing attention in the field of wireless personal communication and digital multimedia broadcasting. It can cope with channel frequency selectivity due to its own capabilities of overcoming the asynchronous nature of multimedia data traffic and higher capacity over conventional multiple access techniques.

On the other hand, multicarrier modulation schemes are based on the transmission of a given set of signals on large numbers of orthogonal subcarriers. Due to the fact that the multicarrier modulated (MCM) signal is a superposition of many amplitude modulated sinusoids, its probability density function is nearly Gaussian. Therefore, the MCM signal is characterised by a very high peak-to-average power ratio (PAPR). As a result of the high PAPR, the MCM signal is severely distorted when a nonlinear high power amplifier (HPA) is employed to obtain sufficient transmitting power. This is very common in most communication systems, and decreases the performance significantly. The simplest way to avoid the nonlinear distortion is substantial output backoff (OBO) operating in the

linear region of the HPA. However, because of the high OBO, the peak transmit power has to be decreased. For this reason, many linearisation techniques have been proposed to compensate for the nonlinearity without applying high OBO. The predistortion techniques have been known and studied as one of the most promising means to solve the problem. In this thesis, an improved memory mapping predistortion technique devised to reduce the large computational complexity of a fixed point iterative (FPI) predistorter is proposed, suitable especially for multicarrier modulation schemes. The proposed memory mapping predistortion technique is further extended to compensate for nonlinear distortion with memory caused by a shaping linear filter. The case of varying HPA characteristics is also considered by using an adaptive memory mapping predistorter which updates the lookup table (LUT) and counteracts these variations. Finally, an amplitude memory mapping predistorter is presented to reduce the LUT size.

Channel coding techniques have been widely used as an effective solution against channel fading in wireless environments. Amongst these, particular attention has been paid to turbo codes due to their performance being close to the Shannon limit. In-depth study and evaluation of turbo coding has been carried out for constant envelope signaling systems such as BPSK, QPSK and M-ary PSK. In this thesis, the performance of TTCM-OFDM systems with high-order modulation schemes, e.g. 16-QAM and 64-QAM, is investigated and compared with conventional channel coding schemes such as Reed-Solomon and convolutional coding. The analysis is performed in terms of spectral efficiency over a multipath fading channel and in presence of an HPA. Maximum a-priori probability (MAP), soft output Viterbi algorithm (SOVA) and pragmatic algorithms are compared for non-binary turbo decoding with these systems. For this setup, iterative multiuser detection in TTCM/MC-CDMA systems with M-QAM is introduced and investigated, adopting a set of random codes to decrease the PAPR. As another application of TTCM, the performance of multicode CDMA systems with TTCM for outer coding over multipath fading channels is investigated.

To achieve a high channel coding gain, received signals have to be equalised to eliminate

intersymbol interference (ISI) at the receiver. Equalisation for OFDM systems is most commonly performed in the frequency domain through least mean squares (LMS) and proportional approaches. In this thesis, an improved LMS equalisation is proposed and compared to the performance of a conventional LMS equaliser. Computer simulations confirm that the performance of the modified LMS equaliser achieves faster convergence and better bit error rate (BER) performance than the conventional one. Turbo equalisation, which is based on a combination of turbo decoding and equalisation, has recently been studied in near optimum receivers for a binary transmission case. This thesis looks into the performance of TTCM-equalisation (TTCM with a MAP equaliser) for M-ary QAM. Algorithm complexity is further reduced by utilising modified MAP equalisation with blind channel estimation by expectation maximisation (EM). This structural improvement is achieved by sharing common information amongst both algorithms. Finally, a blind TTCM-equalisation technique for M-QAM in an unknown channel is introduced and its performance is compared to the case of a known channel.

Acknowledgements

I would like to thank my supervisor, A/Prof. Sam Reisenfeld, for his valuable ideas, suggestions, constructive discussions and guidance in preparing this thesis during a difficult time. Moreover, my gratitude goes to the members of the Cooperative Research Center for Satellite System (CRCSS) and my fellow PhD students for offering help and friendly advice throughout my research. Finally, I am very grateful to my wife and the role she has played in my life supporting me as PhD student in a foreign country - she is the reason that my research is successful. She has always been my closest friend and encouraged me through her dedication and patience when I needed it most.

List of Acronym

AM:	Amplitude Modulation
APP:	A Posteriori Probability
AWGN:	Additive White Gaussian Noise
BCH:	Bose Chaudhuri Hoequenghem
BCJR:	Bahl Cocke Jelinek Rajiv
BER:	Bit Error Rate
BPSK:	Binary Phase Shift Keying
DAB:	Digital Audio Broadcasting
DS-CDMA:	Direct Sequence Code Division Multiple Access
DSP:	Digital Signal Processing
DVB:	Digital Video Broadcasting
EGC:	Equal Gain Combining
EM:	Expectation Maximization
EQ:	Equalizer
FEC:	Forward Error Correction
FFT:	Fast Fourier Transform
FPI:	Fixed Point Iteration
GF:	Galois Field
HPA:	High Power Amplifier
IBO:	Input Back Off
ICI:	Inter Carrier Interference

IFFT:	Inverse Fast Fourier Transform
IMT 2000:	International Mobile Telecommunication 2000
ISI:	Inter Symbol Interference
LLR:	Log Likelihood Ratio
LMS:	Least Mean Square
LUT:	Look Up Table
MAP:	Maximum A priori Probability
MC-CDMA:	Multi Carrier Code Division Multiple Access
MCM:	Multi Carrier Modulation
ML-MD:	Maximum Likelihood Multi user Detection
MMSE:	Minimum Mean Square Error
MRC:	Maximum Ratio Combining
MRC-MUD:	Maximum Ratio Combining Multi User Detection
MSE:	Mean Square Error
OBO:	Output Back Off
OFDM:	Orthogonal Frequency Division Multiplexing
PAPR:	Peak to Average Power Ratio
PD:	Pre Distorter
PDF:	Probability Density Function
PM:	Phase Modulation
PN:	Pseudorandom Noise
PSK:	Phase Shift Keying
QAM:	Quadrature Amplitude Modulation
RAM:	Random Access Memory
RDP:	Ram Data Point
RMSE:	Root Mean Square Error
RS:	Reed Solomon
SISO:	Soft Input Soft Output
SNR:	Signal to Noise Ratio

SOVA:	Soft Output Viterbi Algorithm
SSPA:	Solid State Power Amplifier
TCM:	Trellis Coded Modulation
TD:	Total Degradation
TTCM:	Turbo Trellis Coded Modulation
TWTA:	Travelling Wave Tube Amplifier
VA:	Viterbi Algorithm
VLSI:	Very Large Scale Integrated
WLAN:	Wireless Local Area Network

List of Symbols

$A(\cdot)$	Amplitude of a HPA output
A_{MAT}	Autocorrelation matrix used for the EM algorithm
A_{RAM}	RAM memory address used for the memory mapping predistorter
$\mathbf{A}_{\mathrm{sat,I}}$:	Maximum input saturation power
$\mathbf{A}_{\mathrm{sat,O}}$:	Maximum output saturation power
b_k	k-th bit
B	Block size
C_{EQ}	Equaliser coefficients
C_{ORG}	Second orthogonal code used for multicode CDMA systems
C_{PAPR}	Random code used for MC-CDMA systems to reduce PAPR
C_{VEC}	Cross-correlation matrix used for the EM algorithm
$\mathrm{DET}\lvert\cdot\rvert$:	Determinant of matrix
$\mathrm{D}_{\mathrm{VEC}}$:	Decision vector used for RS decoding
e	Error value used for LMS equalisation
E_a	Estimated average symbol energy in a Rayleigh fading channel
El_m	Error location value used for RS decoding
d_k	k-th symbol
D_{CON}	Convolutional Depth, which is the number of symbols given to decode one symbol at the convolutional decoder
f_c	Carrier frequency (RF)
G_{MC}	Processing gain of multicode CDMA systems
g	Linear gain of a HPA

$g_{\mathrm{GF}}(D)$:	Polynomial function
H	Channel coefficients vector in frequency domain
I	Number of iteration used for iterative decoding
$Im\{\cdot\}$	Imaginary part of a complex value.
K_{SYM}	K-number of symbols
K_b	the number of bits
K_{CON}	Constraint length for a recursive encoder
L	Number of coefficients of a linear filter
La_k^{e2}	k-th a priori probability to decoder 2
Le_k^{e1}	k-th extrinsic information from decoder 1
$\mathbf{Map}(\cdot)$	Channel mapping function
M_{LUT}	Look-up table (LUT) size
M_{PATH}	Path matrix used for the SOVA algorithm
M_{sym}	Number of symbols for M-ary QAM
N_{FFT}	The number of FFT points
N_p	First orthogonal code length of a multicodes-CDMA system
N_{POS}	Position number used for S-interleaver
N_w	First orthogonal code length of a multicodes-CDMA system
$O(\cdot)$	Output of a predistorter
P_e	Bit error probability
$p_T(\cdot)$	a unity rectangular function
$\mathbf{P}_{\mathrm{IN}}$	Average HPA input signal power
$\mathbf{P}_{\mathrm{OUT}}$	Average output signal power
$P(X_k = d_k)$	Log likelihood probability used for EM algorithm
$r_1^{K_{\mathrm{sym}}}$	K_{sym} number of received symbols
R	Data rate
$Re\{\cdot\}$	Real part of a complex value.
S	Number of status
$S_{m,\mathrm{SYN}}$	m-th syndrome used for Reed-Solomon code

T_b	Bit duration
T_c	Chip duration of CDMA systems
T_d	Propagation delay of a multipath channel
t_{ER}	Number of error correction for Reed-Solomon code
T_{FFT}	FFT integration period
T_{GI}	Guard interval
T_s	Sampling period
T_{SYM}	Symbol duration
U	Number of users
$W[n]$	n-th orthogonal code
$x[n]_{\mathrm{Norm}}$	Normalised input to a predistorter
α^{ch}	Channel attenuation factor
$\Phi(\cdot)$	Phase distortion of a nonlinear HPA
ξ	Convergence constant
$\Lambda(\cdot)$	Log-likelihood ratio (LLR)
α_{GF}	A primitive element of $GF(2^m)$
$\alpha_k(s)$	Forward probabilities used for turbo decoding
$\gamma_k(m, s)$	Transition probabilities used for turbo decoding
$\beta_k(s)$	Backward probabilities used for turbo decoding
ψ	a complex Gaussian noise
κ	Number of iterations used for a FPI predistorter
Ψ	a complex Gaussian noise in frequency domain
Δ	Channel mapping values used for iterative multiuser detection
σ_c^2	Channel variance
ζ	a constant used for pragmatic TTCM decoding
$\otimes$	matrix multiplication

Contents

List of Figures